

## Letters to the Editor: Comment and Reply

### Comment

#### Waste Treatment in Product Specific Life Cycle Inventories

Part I: "Incineration" by Markus Kremer, Gertraud Goldhan and Michael Heyde, *Int. J. LCA* 3 (1) 47-55 (1998)

Part II: "Sanitary Landfill" by Jürgen Bez, Michael Heyde and Gertraud Goldhan, *Int. J. LCA* 3 (2) 100-105 (1998)

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In the 1998 issues 1 and 2 of the *International Journal of LCA* the Fraunhofer Institute in Freising, Germany, published two articles concerning waste treatment in product specific Life Cycle Inventories (LCI). In the first paper the authors describe a model for the calculation of inventory data concerning an incineration plant (KREMER et al., 1998). The second paper refers to the disposal of waste in sanitary landfills (BEZ et al., 1998). Both articles lack a literature review. Thus we will try to give an overview of existing models in this letter and compare them to the Fraunhofer model. We will restrict our comments to the first article (KREMER et al., 1998).

As KREMER et al. (1998) correctly point out in their introduction, many studies of the past exclude waste treatment in the inventory analysis due to a lack of a well functioning allocation model. Unfortunately it is not mentioned in the article that this gap was already discovered a few years ago, which led to the development of several waste treatment models in various countries. In this letter we want to outline four European models, which all allow a product specific assessment of waste treatment.

In Germany, the ifeu Institute in Heidelberg developed a model for incineration, sanitary landfills, and waste water treatment back in 1994. The model was first used and described in a Life Cycle Assessment study of packaging materials (FRANKE et al., 1994). This incineration model considers the incineration process including a wet/semi-dry flue gas purification system, the landfilling of slag, the gathering as well as the transportation of waste. It also calculates the amounts of some ancillary inputs (i.e.,  $\text{Ca}(\text{OH})_2$  and water) but disregards the emissions and resource use resulting from their production. When calculating the waste input related emissions of the incineration, the ifeu-model distinguishes between waste types with different contents of inert substances. In 1996, the ETH Zurich in Switzerland also developed a model for incineration, sanitary landfills, and waste water treatment (ZIMMERMANN et al., 1996). This model was, for instance, used for the calculation of packaging inventory data (BUWAL, 1996), which are now part of the new Simapro Software. The incineration process (wet flue gas purification), landfilling of incineration residues, production of pro-

cess materials, infrastructure, the gathering as well as the transportation of waste are part of the system boundaries. Recently the incineration model was renewed, now differentiating between transfer coefficients<sup>1</sup> for inert and burnable waste materials (HELLWEG, 1998; HELLWEG et al., 1998). The software tools (Excel) and the report (ZIMMERMANN et al., 1996) can be ordered by the public, providing a tool to calculate end-of-pipe inventory data.

The TNO Institute in The Netherlands has published several articles dealing with the allocation of waste treatment models (e.g. EGGELS and VAN DER VEN, 1994; EGGELS and VAN DER VEN, 1995). Their model is briefly described in (UDO DE HAES and VAN HALEN, 1997), with a comprehensive publication being in progress. The TNO-model considers the incineration process (flue gas purification with closed water cycle) and the landfilling of incineration residues. Similar to the above-described models, TNO distinguishes between inert and burnable waste input fractions.

Also in 1997, the Swedish Environmental Protection Agency published a report on solid waste treatment in LCA with reference to incineration and sanitary landfills (SUNDQVIST et al., 1997; SUNDQVIST, 1998). The product related incineration emissions/outputs are calculated with factors based on linear relationships. Here, the landfill model for incineration residues makes a difference between the surveyable time period and the time period afterwards.

In contrast to the Fraunhofer model (FRANKE et al., 1994), all models outlined above consider the landfills for slag to be part of the system. However, the models vary much in regard to the time period under consideration and the sum of anticipated emissions. The range varies from considering the emissions within the first decades, as performed in the TNO model<sup>2</sup>, to indefinite time horizons (ZIMMERMANN et al., 1996; SUNDQVIST et al., 1997). The workshop "Systems Engineering Models for Waste Management" in Göteborg, Sweden (25 - 26/02/1998), pointed out that the long term behavior of landfills is a major issue. We fully agree with

<sup>1</sup> factors representing the relationship between waste input and emission/residue output

<sup>2</sup> oral conversation with B. van der Ven, P. Eggels, and B. Rijpkema, Apeldoorn (NL), February 17, 1998

this point, as the life cycle approach should consider all emissions from cradle to grave. Subsequently it does not allow cutting off emissions after a certain time period in our opinion. Moreover, recent LCA studies showed that the impacts of the landfills for incineration residues outdo the impacts caused by the incineration process itself by far (HELLWEG et al., 1997) so that these landfill impacts should not be neglected. These results are maybe even underestimated, as the ETH model only considers the "predictable amount of emissions" drawn from availability tests whereas there are also advocates for considering all landfill components as future emissions<sup>3</sup>. Authors from the area of substance flow analysis have already discovered the importance of landfill emissions in comparison to air emissions a few years ago (BACCINI et al., 1993). As a consequence, we regard the non-mentioning of a landfill model for incineration residues in the Fraunhofer model to be a major deficit.

There is common agreement on basic allocation aspects like the differentiation between process and product related emissions. Process related emissions are independent from the waste input and will therefore be accounted to the overall waste. In contrast to this, product related emissions are caused by certain input components of the waste. The assignment of emissions to either one of those two groups is fairly similar in all models. However, there are a few exceptions; e.g., the NO<sub>x</sub> emissions which can be formed by several reaction paths (fuel NO<sub>x</sub>, thermal oxidation, prompt NO<sub>x</sub>-formation). In the different models they are either characterized as product dependent (UDO DE HAES and VAN HALEN, 1997), as process dependent (KREMER et al., 1998; FRANKE et al., 1994) or as a combination of both (ZIMMERMANN et al., 1996; SUNDQVIST et al., 1997). In general, the regular temperatures in an incinerator do not reach the lower limit for thermal oxidation except in some hot spots. Therefore we think that it is not justified to consider all NO<sub>x</sub> emissions as process dependent as done in the Fraunhofer model.

Concerning the product specific emissions no consensus has been reached yet on whether the relation of waste input and emission output can be represented by constant transfer coefficients. Ifeu, TNO, and ETH consider a carefully applied adaptation of the transfer coefficients to be helpful for a better representation of the real happenings, whereas the Swedish and the Fraunhofer model work with linear relationships and thus do not differentiate between different waste input materials. In our opinion a distinction between inert and burnable fractions of the waste should be taken into account. Otherwise the fact that inert waste is generally transferred to the slag is not included in the model, neglecting known causal relationships.

KREMER et al. (1998) note that the transfer coefficients in their table 1 from the Würzburg MSW were "cross-checked with literature data", unfortunately they do not say which literature they used. We compared the coefficients with some of our literature data (BELEVI, 1998; MORF et al., 1997; BELEVI, 1994; REIMANN et al., 1989; SCHNEIDER, 1987), and did not find matching data for some of the coefficients, e.g. the co-

efficient for Cd to grate ash (which is very high). Moreover, many substances are missing in Table 1 whereas others are not used in the calculation.

With regard to the flue gas treatment, the Fraunhofer model considers the clean gas emissions as constant and allocates them to the flue gas volume. This approach is different from the approach used in the other models, which use transfer coefficients also for this part of the calculation. Certainly the reasoning of KREMER et al. (1998) is justified, as the clean flue gas emissions really do not vary much with the waste input.

Like the other models, KREMER et al. (1998) allocate the energy production to the lower heating value of input substances. They propose a calculation from the elementary composition of the waste according to the formula of Boie. Although this procedure is theoretically correct, we would rather advise to take the heating value from the energy balance of the incineration plant by comparing the amount of produced steam to the amount of input waste. In Switzerland, the calculation of the heating value according to the formula of Boie would result in a heating value of 6.6 MJ/kg, whereas it is almost 11 MJ/kg in reality (LEMAN, 1994). Values for single input materials are available from literature as well, e.g. see list in ZIMMERMANN et al. (1996).

From the above mentioned points we conclude that the Fraunhofer model does not offer major improvements to already existing models, but shows some major deficiencies instead. The main problem is the neglecting of the emissions resulting from the landfills of incineration residues, which outdo the emissions from incineration. In their introduction KREMER et al. (1998) criticize that many LCA studies only list the amount of generated waste, but on the other hand they also only list the amount of produced incineration residues without considering the potential emissions (see Tables 6 and 7). In general, this procedure is only a small improvement in comparison to completely excluding impacts resulting from waste generation. The incineration model itself is not very well explained and does not show advantages to other existing models. Furthermore, the chosen literature is neither complete nor up to date.

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<sup>3</sup> E.g. oral statement of G. Finnveden (Dep. of Systems Ecology, Stockholm University, Sweden) on the workshop "System Engineering Models for Waste Management" in Göteborg, Sweden (25-26/02/1998)

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## Reply

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We highly appreciate that the international discussion on our approach of material related modelling in the area of waste management is opened by the comments from S. HELLWEG and S. MÖSSNER on our publication "Waste Treatment in Product Specific Life Cycle Inventories, Part I: Incineration (*Int. J. LCA* 3 (1) 47-55 (1998)), Part II: Sanitary Landfill (*Int. J. LCA* 3 (2) 100-105 (1998))". These comments include a lot of suggestions which can be very useful for improving our process model. Nevertheless, we would like to reply on some points of criticism and misunderstanding contained in these comments.

HELLWEG and MÖSSNER criticise that no former publication on the subject of our publication is discussed or mentioned. They refer to some other approaches of material related modelling in the area of waste management and indicate the corresponding literature. The approach of the ifeu Institute was developed by ifeu in a joint project of ifeu, GVM and our Institute in 1994. The deficits of this model approach were the incentive for the development of our own incineration model. The other approaches mentioned are described by workshop proceedings and reports which are unfortunately not available for us until now. Furthermore, most of the publications mentioned by HELLWEG and MÖSSNER were published after we had finished our publication, Part I of which on "Incineration" was submitted in March 1997.

HELLWEG and MÖSSNER criticise that the further treatment of the slag from the waste incineration is not included in the model. With regard to this criticism, the goal of our approach – the material-related description of the effects of the waste incineration – has to be pointed out. Starting from this goal definition, the system boundaries for the calculation of the energy and material balance have to be defined. As shown in Figure 3 and 4, the slag is an output flow of the system studied and the treatment of the slag is located outside the system described by the model. For example, in the case of disposing the slag on a municipal landfill site, the environmental impacts resulting from the treatment of the slag could be calculated by the approach described in Part II on "Sanitary Landfill".

Furthermore, the modelling of the formation of  $\text{NO}_x$  in the furnace as exclusively depending on process parameters (temperature, air excess, etc.) is criticised. This objection is justified but it is of minor relevance if we take the system boundaries into consideration. As an output value of our process model, the concentration of  $\text{NO}_x$  in the clean gas (and not in the raw gas) is calculated, which is only process dependent, as the emissions in the clean gas after flue gas purification are assumed to be no longer depending on the input composition. This assumption has to be limited when looking at substances like HCl or  $\text{SO}_2$ . For these substances, it has to be checked whether the elements which cause their formation are contained in the fuel. If, e.g. no chlorine is contained in the specific fuel under consideration, no HCl emissions will be allocated to the incineration of this specific fuel. The allocation of slag to an ash-free input, as implied in the comments, is also impossible. The distribution of the incombustible fraction of the input to the output flows is calculated due to transfer coefficients as shown in Figure 5.

The references have to be completed by the data sources we used for comparing the transfer coefficients derived from data measured at the Wuerzburg MSWI. These data sources are included in the references [2] and [8].

With regard to the allocation of the energy produced in the waste incineration, it is suggested in the comments to compare the amount of steam produced to the amount of waste input. This approach does not answer the question which part of the steam produced can be allocated to a special waste fraction. This question is of major importance to the assessment of waste incineration in the context of product LCI and it can only be answered when the calorific value of the special waste under study is known. The calorific value has to be calculated by a theoretical approach if it is not known from experimental or literature sources. For the determination of the calorific value of solid fuels, the formula of BOIE is commonly used and the values calculated with this formula show a good correspondence to the measured values.